

## BLIND SPOT MAY REVEAL VACUUM RADIATION

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Back in the 1970s Stephen Hawking of Cambridge University in the UK made the theoretical discovery that small black holes are not “completely black”. Instead, a black hole emits radiation with a well-defined temperature that is proportional to the gravitational force at its surface. The finding uncovered a deep connection between gravity, quantum mechanics and thermodynamics. And later, Bill Unruh of the University of British Columbia in Canada proposed that quantum particles should emit thermal radiation in a similar way when they are accelerated. According to Unruh, a particle undergoing a constant acceleration would be embedded in a “heat bath” at temperature  $T = \frac{\hbar}{2\pi ck} \cdot a$ , where  $\hbar$  is the Planck constant divided by  $2\pi$ ,  $a$  is the acceleration,  $c$  is the speed of light and  $k$  is the Boltzmann constant. But is it really possible to detect such radiation? Recently, Pisin Chen of the Stanford Linear Accelerator Center and Toshi Tajima of the University of Texas at Austin in the US have suggested that it should be possible to detect the Unruh radiation emitted by electrons that are accelerated by high intensity lasers (1999 Phys. Rev. Lett. 83 256). The difficulty with detecting Unruh radiation is that enormous accelerations are required to produce a measurable effect. For instance, we would have to accelerate a particle to over  $10^{20}$  m/s<sup>2</sup> to generate a temperature of 1 K. Recent advances in laser research mean that lasers can now deliver subpicosecond pulses with petawatts of power. These could produce accelerations that are  $10^{25}$  times greater than the acceleration due to gravity at the Earth’s surface, and two orders of magnitude larger than previous experimental proposals. At the quantum level, the vacuum is full of particles and antiparticles that constantly appear and disappear. The Heisenberg uncertainty principle allows these “virtual” particles to exist for a very brief moment of time before they recombine and disappear into the vacuum again. According to Hawking if a particle and antiparticle are created close to the surface of a black hole, the strong gravitational force will pull one of the particles into the hole while the other escapes. Thus the black hole can produce “radiation from nothing”. Similarly, Unruh radiation comes from the quantum vacuum. The curious feature about Hawking radiation is that the temperature is inversely proportional to the mass of the emitting source. The only black holes that may be detectable are “miniholes” that may have been formed shortly after the Big Bang. Such black holes would have a mass of  $10^{15}$  grammes and would be smaller than a single atom. The Unruh effect is considered slightly less esoteric, and in the

1980s several groups proposed experiments to detect the radiation. Unruh himself suggested that sound waves would propagate in a supersonic fluid flow in the same way that quantum fields propagate in the vicinity of a black hole. And shortly afterwards the late John Bell and Jon Leinaas of the University of Oslo in Norway suggested that the Unruh effect would alter the motion of particles at high-energy accelerators. A more realistic experiment was suggested by Joseph Rogers, now at Cornell University in the US, in which an electron confined by electric and magnetic fields in a so-called Penning trap would give a signal. Meanwhile Eli Yablonovitch, now at the University of California at Los Angeles proposed that Unruh radiation would be produced when a gas is suddenly ionized and turns into a plasma. And Simon Darbinyan of the Yerevan Physics Institute in Armenia and co-workers suggested that Unruh radiation could be produced by a beam of particles propagating through channels in a crystal lattice. In all of these experiments, however, the Unruh signal would be buried beneath a much larger background signal, a problem that Chen and Tajima have managed to circumvent. Moreover, in their scheme an electron can be instantly accelerated and decelerated in every laser cycle. Chen and Tajima present simple calculations for the acceleration produced by a standing wave produced by two counter-propagating, ultra-intense laser pulses. They propose to detect the Unruh radiation from a minute change to the classical Larmor radiation emitted when an electron is accelerated. Despite the high acceleration produced in a petawatt laser, the power of the emitted Unruh radiation is several orders of magnitude smaller than the power of the Larmor radiation. However, Chen and Tajima calculated the angular distribution of both types of radiation and found a “blind spot” where the Unruh signal would dominate over the Larmor radiation (see figure). Although appealing, the proposal of Chen and Tajima is based on several assumptions that may not actually be true. For example, they assume that the electron has a well-defined acceleration, velocity and trajectory. Moreover, in 1988 Alexander Nikishov and Vladimir Ritus of the Lebedev Physical Institute in Moscow suggested that the Unruh heat-bath concept could not be tested using charged particles in an electric field. They argued that the particle and antiparticle pairs created from the vacuum would encounter a varying acceleration field over a short timescale, whereas Unruh radiation is related to constant accelerations only. And at a recent workshop on the quantum aspects of beam physics, John Jackson from the University of California at Berkeley warned against trying to interpret conventional phenomena in terms of Unruh radiation. Nevertheless it is challenging to look for new ways to test quantum field theory that may give an insight into the physical origin of Hawking radiation.

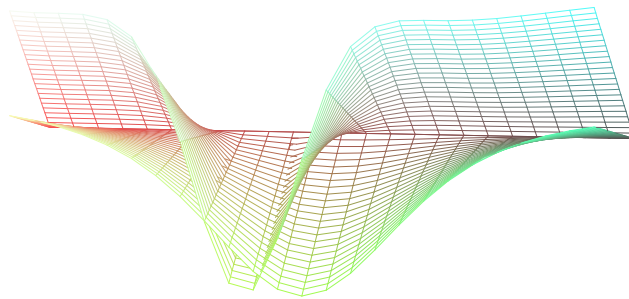


Figure: The angular distributions of the Larmor (top) and Unruh radiation (bottom) emitted by an accelerated electron. In general the power of the background Larmor radiation is much greater than the Unruh signal, but there is a small “blind spot” where the Unruh radiation dominates.